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by

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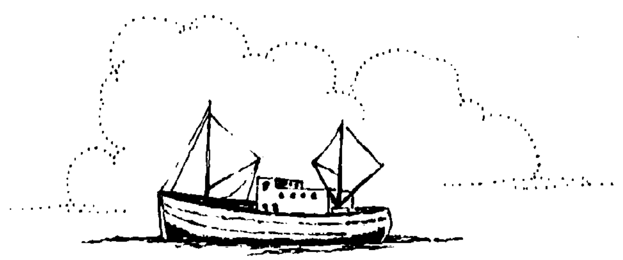

ST. GEORGE'S WEST, BERMUDA

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by

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INTRODUCTION

A study of animal-sediment interrelationships on the Bermuda slope was initiated during the summer of 1961 on a research contract to the Bermuda Biological Station from the Office of Naval Research (#Nonr-1135(02)). Analytical work on the samples was carried out during the academic year 1961-62 at Lehigh University and the Woods Hole Oceanographic Institution under sponsorship of the Petroleum Research Fund of the American Chemical Society and the National Science Foundation.

The purpose of the study was to determine, in as quantitative a manner as possible, the composition of the benthic fauna and associated carbonate sediments, and the variation in these with increasing depth and distance from land. It was hoped that from the study interrelationships between the organisms and the substrate could be established.

The field work involved a bathymetric survey of a portion of the southeastern Bermuda slope and sampling for sediments and organisms within this area. Analytical work included texture and mineralogy of the sediments, and biological makeup of the sedimentary particles and the living infauna.

FIELD PROGRAM

The field program consisted of three phases: (1) bathymetric surveying, (2) grab sampling of sediments at depths less than 400 fathoms, and (3) collection of animals and sediments by dredging below 400

fathoms. Sampling extended from shallow water, near shore, to a depth of 1350 fathoms about eight miles southeast of Bermuda. The R/V PANULIRUS of the Bermuda Biological Station was employed in the bathymetric surveying and sampling.

Bathymetry

A detailed bathymetric survey was made of an area approximately two miles wide, extending eight miles offshore in a southeasterly direction from Castle Harbor. Thirty-six miles of continuous EDO profiling provided the bathymetric coverage. Positioning was accomplished by transit sights taken every five minutes from control points at Paynter's Hill and St. David's Light on land. The area studied, bathymetry and fathogram coverage are shown in Figure 1.

Grab Sampling

Sample stations among the rocks and reefs near shore are indicated as SR (South Reef) in Figure 1. These samples were taken with a 6" by 12" Van Veen grab, then dried rapidly and stored in plastic bags.

Samples from 10 to 400 fathoms on the south slope, SS in Figure 1, were taken with a 9" by 18" Van Veen grab. These samples, which contained significant quantities of silt and clay, were placed immediately in alcohol and kept wet until they were ready for analysis. It has been our experience that such cohesive materials cannot be completely disaggregated once they have been allowed to dry.

Dredging

The three samples from below 400 fathoms, indicated as DS in Figure 1, were taken with a modified anchor dredge designed to collect the top eight centimeters of an area of one square meter or more (Sanders, un-

published). The large sample size is necessary for quantitative faunal collecting in areas of sparse populations. A one quart subsample was taken from the dredge and frozen immediately, and the remainder was washed by gentle elutriation through an 0.3 mm sieve. Organisms, alive and undamaged, were thus separated and immediately placed in buffered formalin for preservation.

LABORATORY STUDIES

Sediment Analysis

The sediments were analysed for grain size distribution, mineralogy, and biological origin of the skeletal grains.

Grain Size -- Calcareous sediments are physically fragile and susceptible to solution in aqueous media. Standard size analysis techniques used for common non-carbonates are not suitable for carbonates. For this reason, new techniques were developed specifically for the carbonates. These are described below.

The sediments were first soaked overnight in 10 per cent hydrogen peroxide to remove organic matter. They were then wet sieved through a nest of screens, having hole sizes 4000, 500 and 62μ. Treatment was rapid and as gentle as possible in order to minimize breakage. A true size separation by sieving is impossible with skeletal material because many of the hollow forms -- Foraminifera, gastropods, pteropods, etc. -- are full of fine sediments which cannot be removed short of destroying the shells. Rapid, gentle wet sieving appears to be the best compromise.

The material which passed through the 62 micron screen was collected in a bucket where the pH of the slurry was adjusted to higher than 8 with

ammonium hydroxide. Because of the high and variable solubility of the mineral forms of calcium carbonate at pH's below 8, (see Revelle and Fairbridge, 1957; Chave et al, 1962) it was necessary that a high pH be maintained through the whole operation.

A pipette separation was carried out on the fraction smaller than 62 microns. Ammonium hydroxide was used to disperse the sediment, for normal phosphate dispersing agents would not be used in the columns because these, when dried, interfered with later X-ray analyses.

The pipette separations were based on standard quartz settling times. Clearly, the carbonate particles, which range in mineral density from 2.71 to 2.93, and which deviate greatly in spherical shape, will not settle at the same rates as round quartz grains of density 2.65. Nonetheless, this technique appeared most suitable.

Following the size fractionation by sieve and pipette, the samples were dried as rapidly as possible at temperatures below 90° C. and weighed. This precaution is necessary because the unstable mineral forms of $CaCO_3$ have a strong tendency to change to stable calcite at high temperatures, in the presence of water.

The dried samples were weighed, ground in a mortar, and smeared on a glass microscope slide in preparation for X-ray analysis. A split of the coarser fractions was saved for microscopic examination.

Size analyses of the sediments are shown in Table 1.

Mineralogic analysis -- Calcareous skeletal materials and the sediments derived from them are composed of the minerals calcite, aragonite and a spectrum of magnesium calcites (Chave, 1952). The various minerals have characteristic X-ray diffraction spectra, such that, even in complex

mixtures, quantitative mineralogic analysis is possible from spectral interpretation.

The carbonate minerals which occur in marine sediments have prominent diffraction lines which lie between 26° and 31° 2θ when copper Kα radiation is used. A typical diffraction pattern of a Bermuda sediment is shown in Figure 2. Two aragonite lines, or peaks, occur at 26.25° and 27.25° 2θ. A broad and complex calcite peak occurs between 29.3° and 30.2° 2θ. This peak results from the presence of calcite and a variety of magnesium calcites. Pure calcite has a peak at about 29.4°. Magnesium in solid solution in the crystal lattice causes the peak to shift to slightly higher angles. This is a result of the decrease in interplanar spacing due to the smaller ionic radius of magnesium relative to calcium. The complex calcite peak shown in Figure 2 indicates that magnesium calcites of several compositions are present in the sample.

Mineralogic analysis was carried out by integrating the intensity of the diffracted X-radiation at the various angles. The per cent aragonite in the sample is determined using a calibration curve prepared from standards made up of a variety of natural skeletal materials -- aragonite, calcite and several magnesium calcites. The curve is shown in Figure 3. The method for obtaining this value is shown in Figure 2. The integrated aragonite intensity, 25.75° to 26.75°, less background at 25.75°, divided by the total calcite intensity, 29.0-30.5°, less background, gives the ratio shown in Figure 3. Thus, the aragonite percentage is determined from the empirical curve using the following computation:

$$B - 2A / (D + E) - (C + F).$$

The deviation of the points from the calibration curve is largely a result of imperfect mixing of the weighed minerals. There is no evidence that the amount of magnesium in the calcite affects the calibration.

A measure of the nature of the mixture of magnesium calcites is obtained by integrating the calcite diffraction peak in two parts -- 29.0° to 29.75°, and 29.75° to 30.5° 2θ. The ratio of these two values, less background, is a ratio of "High" to "Low" magnesium calcite. The calculation is as follows:

$$\text{High/Low Mg Calcite} = E - \frac{(C + F)}{2} \Big/ D - \frac{(C + F)}{2}$$

The value obtained by this method is approximately the ratio of the amount of calcite in the sample which contains more than 8 weight per cent $MgCO_3$ to that containing less than 8 per cent.

The two mineralogic parameters obtained from X-ray diffraction analysis are 1) percent aragonite, and 2) ratio of high to low magnesium calcite. The mineralogic analyses of the sediments are shown in Tables 2 and 3.

<u>Sediment Biology</u> -- The sediments from the reef tract and the slope are composed almost entirely of calcareous skeletal materials of marine organisms. In a few of the samples fragments of Pleistocene rock are found. The biologic nature of the skeletal parts making up the coarser fractions was determined by microscopic examination. Estimation of the biologic nature of the finer fractions, less than 62 microns, from the X-ray data is discussed in a later section.

There are four possible sources for the calcareous material of the sediments in the study area. These are 1) Pleistocene outcrops on the

shore or perhaps underwater on the slope, 2) organisms living on the reef tract (0 - 10 fathoms), 3) benthic organisms living on the slope below 10 fathoms, and 4) planktonic organisms living in the water column. In many cases one can estimate, quite accurately, the source of a particular sediment grain. In a few cases, for instance echinoderm fragments and serpulid worm tubes, the source is difficult to assess. Table 4 lists the common skeletal parts found in the sediments and their probable source.

The biologic composition of the coarser fractions of the sediments is given in Table 5. The data are listed only semi-quantitatively as: "dominant" (D) (greater than about 35%); "abundant" (A) (20 - 35%); "common" (C) (5 - 20%); and "rare" (R) (less than 5%).

Living Organisms -- Preserved specimens from the washed DS samples were counted. The number of specimens and the percentage of the fauna composed of polychaetes is shown in Table 6. Identification of the specimens, a lengthy process involving specialists from various parts of the world, is just getting started and will take several years to complete.

DISCUSSION OF RESULTS

Bathymetry

The study area, Figure 1, can be divided into three distinct bathymetric zones -- the reef tract, the steep slope from 10 to 400 fathoms, and the terraced gentle slope below 400 fathoms. On the reef tract, above the 10 fathom contour, the bottom is extremely rugged. Sheer rock or reef walls, often overhanging, separate level sandy patches at

a depth of approximately 10 fathoms, from rocky surfaces at 3 - 7 fathoms. The sandy patches at 10 fathoms, a common depth throughout the Bermuda platform, probably record a standstill in sea level during late Pleistocene time. Terraces at 10 fathoms are common the world over. If this represents a planed marine terrace, the reefs in the area must have grown up since very late Pleistocene time, in less than 10,000 years.

The bathymetry run over the reef tract during this and other studies suggests that there are few, if any, continuous deep (10 fathoms) passages through, from the shore, to the top of the slope. Thus it would appear that transportation of coarse sediments from the shore to the slope would be difficult. Transportation of fines, in suspension, would, of course, be possible.

The slope below the 10 fathom contour is often very steep; usually greater than 45°. In some places, for instance in the vicinity of station SS 11, it is nearly vertical. Sediments are absent on much of the upper slope. At four locations, SS 10, 11, 18, and 20, rock was recovered with the Van Veen grab. At many other locations on the upper slope difficulty was experienced in obtaining any sample with the grab, thus suggesting a rock bottom.

Below 400 fathoms the slope becomes more gentle, roughly 150 fathoms per mile, and it is terraced. Three distinct terraces occur on the east side of the study area at about 450, 850 and 1000 fathoms.

Sediment Distribution

Unconsolidated sediments occur in patches in the reef tract, on part of the upper slope, and over most of the lower slope.

Size Distribution -- Textural variation of the sediment in the study area is shown in Figure 4. The sediments in the reef tract are coarse sand, with the exception of SR 1 which is fine sand, and lack any significant amount of material finer than 62μ. They contain few whole skeletons, being composed mainly of broken corals, coralline algae, Foraminifera, encrusting Bryzoa, and serpulid worm tubes.

Laboratory experiments by Chave (1960, 1962a) have shown that abrading such skeletons in a tumbling barrel produces an abundance of silt sized particles (< 62 microns). If these experiments are comparable to natural conditions of abrasion, the production of coarse and fine sand in the reef tract must have resulted in the formation of abundant fines subsequently transported away from the area. The transportation of the fines must have been largely off shore, for Chave (1962b) reports that reef-like sediments can be found only a few hundred yards landward from the living reefs in Castle Harbor and in the northern Bermuda lagoon.

Seaward from the reefs, at the top of the slope are two interesting occurrences of algal (Lithothamnium?) balls -- SS 1 and SS 17. These balls, which range in size from about 1 to 6 inches in diameter, are nearly round. They appear to be alive, for they exhibit a good pink color and chlorophyll is extracted from them when they are preserved in alcohol. The origin of the algal balls is a puzzle. An interesting feature of their distribution is that they are found only in the vicinity of 30 to 40 fathoms in several parts of Bermuda, on Challenger and Argus Banks, as well as Campeche Bank in the Gulf of Mexico, and several places in the Caribbean. In areas where the balls are found sediments and most

other organisms are absent or rare. More work is necessary before the origin of algal balls is understood.

The heterogeneous distribution of sediment textures down the slope is a result of transport of sediment down the slope from the reef tract, erosion of Pleistocene rock (see Amphistegina lessoni, below), and variation in original skeleton size contributed by organisms in the different areas. The distribution of sediment textures suggests an unstable sedimentary environment, not a classical picture of sediments becoming finer and finer with increasing distance from shore and with decreasing energy.

Mineralogy and Skeletal Types -- The mineralogy and skeletal makeup of carbonate sediments are closely related. As pointed out by Chave (1962b) "The gross mineralogy of the sediments reflects the nature of the calcareous organisms living in and near the area of deposition." The mineralogy of the common calcareous organisms living on the reef tract, slope and in the water column is shown in Table 7.

It is clear from the table that, with the exception of benthic Foraminifera down to 450 fathoms, and echinoids to 400 fathoms, most of the high magnesium calcite in the sediments of the study area is reef-derived in the form of algae, H. rubra and alcyonarian spicules. Serpulid worm tubes contain high magnesium calcite, but these are rare except in the reef tract. Aragonite is produced by organisms living in all of the environments.

The distribution of minerals and recognizable skeletal remains in the study area clearly illustrates the instability of the slope sediments and the important transport of reef materials down the slope.

The mineralogic homogeneity of the finer fractions, Figure 5, and the relatively high magnesium calcite content as deep as station DS 6, suggest that a constant rain of reef-derived fines, transported in suspension, is being contributed to the sediments.

The mineralogic and biologic heterogeneity of the coarser fractions suggests that mass transport (sliding) is an important process of sedimentation in this area. Figures 6 and 7 illustrate tne mineralogic heterogeneity. It is notable that the 4000-500 μ fraction is much more heterogeneously distributed than the 500-62 μ fraction. Perhaps this indicates that some of the fine sand is being carried in suspension in the water.

The extremely heterogeneous distribution of skeletal types in the 4000-500 μ fraction is illustrated in Figure 8. In this figure four easily recognized skeletal types are used as typical representatives of the four possible sources of particles -- Pleistocene-*Amphistegina lessoni*; reef-*Homotrema rubra*; Slope-non-reef benthic Foraminifera; plankton-pteropods.

A. lessoni will be discussed below.

H. rubra, a distinctive and exclusively reef-dwelling, encrusting Foraminifera, which contains a resistant red pigment, was found "common" at the deeper stations SS 7 and 12, as well as at shallow station SS 15. *H. rubra* is widely distributed on the slope, and is even found at the deepest station in the survey, DS 7. Red *H. rubra* has been found by one writer (KEC) in sediment samples 25 miles off Bermuda, beyond the bottom of the slope. The heterogeneity of the sediments is shown by the lack of *H. rubra* at stations SS 6, 9 and 19. Similar patchy distributions of benthic forams and pteropods are shown in Figure 8.

The distribution of carbonate minerals among the various size fractions of the sediments gives additional evidence for the unstable nature of the slope. Chave (1962b) has shown that in physically, relatively stable areas on the Bermuda platform, (and on Campeche Bank), essentially undeviating trends of decrease in aragonite and high magnesium calcite with decreasing grain size occur in sediments in a wide variety of environments. Chave atributes these trends to a slow solutional removal of more soluble skeletal types on the sea floor. No such trends are observed on the Bermuda slope. In fact, commonly, aragonite and high magnesium calcite are more abundant in the $<62\ \mu$ fraction than in the 500-62 μ fraction. This suggests again a constant supply of suspended fines from the reefs and an inconstant supply of sliding coarse material. Apparently the Bermuda slope is so unstable that the sediments do not reach a solubility equilibrium, or pseudo-equilibrium (see Chave _et al_, 1962) with sea or interstitial water.

Amphistegina lessoni -- The distribution of this benthic Foraminifera is a problem in itself. _A. lessoni_ is found living in shallow water in the vicinity of reefs in the Atlantic, Caribbean and Pacific. It is rarely reported as abundant. On the Bermuda slope it is abundant as deep as 400 fathoms, and comprises as much as 50% of the coarse fractions of the sediment at 300 fathoms (SS 4 and 19).

The tests of _A. lessoni_ found in the sediments are almost invariably worn and plastered with a fine-grained encrustation, while most of the other benthic forams are fresh. Further, Chave (1954) reported that specimens from the same general area were composed of low magnesium calcite while all other benthic forams in the same sediments were

high magnesium calcite. These characteristics of A. lessoni on the Bermuda slope suggest that the specimens are fossils. M. G. Gross (personal communication) has shown that some of the Pleistocene eolianites making up the Island are composed predominately of this species.

The problem of how they get on the slope still remains. The present bathymetry of the reef tract probably prevents movement of coarse sediment from the shore to the slope. Two possibilities are suggested: 1) A. lessoni is being eroded from Pleistocene outcrops underwater, near the edge of the slope, or 2) the tests were transported to the slope before the reef tract attained its present configuration. Further work is necessary to resolve the problem of A. lessoni.

Living Organisms

Slope samples (SS) -- The only living organisms observed in the Van Veen grab samples at the SS stations were algal balls at the top of the slope, and a sponge and tubed worm on the slope. No attempt was made to stain and identify living Foraminifera.

Deep samples (DS) -- From available published literature it is apparent that quantitative benthic samples from the deep sea seldom contain as many as 20 living specimens and frequently the samples are devoid of life. Obviously the number of animals available is wholly inadequate for quantitative interpretations. Because the bottom fauna is so scarce, it is necessary to obtain much larger volumes of sediment than previous workers have used.

The anchor dredge used at the DS stations is capable of obtaining almost two square meters of sediment. Using it, deep sea samples have been obtained in the deep Atlantic and on the North American continental

slope as well as on the Bermuda slope. Twenty-two samples have been taken to date.

For purposes of comparison, Table 8 summarizes the results of previous deep sea investigations on this subject. The results to date using the anchor dredge and the elutriation technique described earlier are shown in Table 9.

Each area appears to support its own characteristic number of animals; continental shelf, $6000/m^2$; continental slope, $1500\text{-}3000/m^2$; abyss north of the Gulf Stream, $400\text{-}1000/m^2$; Gulf Stream, $250/m^2$; Sargasso Sea, $25\text{-}100/m^2$; lower Bermuda slope, $100\text{-}300/m^2$; upper Bermuda slope, $500\text{-}1000/m^2$.

Literally thousands of photographs have been taken of the ocean floor with, as one purpose, the estimation of the abundance of benthic life in different areas of the ocean. In order to evaluate the validity of this tool, bottom photographs coincident with the dredge hauls were taken. These pictures indicate that the number of animals seen is only a small fraction of the number present. Furthermore, there is no correlation between the number photographed and the number actually present.

The reason that the camera is unsatisfactory for estimating benthic populations in the deep sea is that the bottom is composed of soft ooze, and the animals live <u>in</u> rather than <u>on</u> the bottom. In the sediment samples studied the epifauna makes up less than one per cent of the total benthos.

With the larger number of animals available from these recent studies, it is possible to examine the question of the nature of benthic deep sea communities. The recent deep sea samples are character-

ized by a marked diversity. The most abundant element is the polychaete worms which usually make up the numerical majority of the fauna and the largest number of species. Crustacea, particularly isopods and tanaids are the second most common group. The phylum Pogonophora is a constant part of the deep sea fauna. Mollusks are represented by solenogastres, pelecypods, gastropods and scaphopods. Sipunculids, echiurids, priapulids, nemertines and Bryozoa are frequently encountered. Anthozoan and hydroid coelenterates, hexactinellid sponges, and echinoderms are occasionally present.

Two of the samples have been divided into their constituent species. In one, HH, 87 species were present of which 54 were polychaetes in a sample of 519 individuals. The most common species comprised 7.7 per cent of the population. At station F there were 1021 individuals, with 126 species, 74 of them polychaetes. The most abundant species formed 7.0 per cent of the population. Thus, the populations exhibit diversity and also a lack of dominance.

A comparison of the structure of these deep sea benthic communities with their shallow water counterparts suggests a method of comparing communities in terms of their diversity and dominance, (see First Conference in Marine Biology, in press). Certain communities, such as littoral boreal assemblages, show pronounced dominance by a few species (Sanders, 1960, 1962). Other communities, as exemplified by the deep sea samples, show no dominance with many species present in approximately equal numbers.

The first type of structure appears to be characteristic of a physically controlled community. In such environments physical conditions, such

as temperature and salinity, fluctuate widely. The second type of community structure appears to be characteristic of a biologically regulated environment. In the deep sea temperature and salinity are constant, light is absent, and even the sediments are remarkably constant over hundreds of square miles.

The non-physically, or biologically controlled community appears to be evolutionarily more mature, resulting from a long period of biological interaction and biological accomodation. The physically controlled community represents an early stage of development, where niche diversifications were not well developed due to physiological stresses brought about by the physical changes in the environment.

The physically controlled community is typical of such environments as hypersaline bays, high arctic terrestrial environments, deserts and most fresh water lakes. Biologically controlled environments, other than the deep sea, may be typified by tropical rain forests and tropical shallow water environments.

ANIMAL-SEDIMENT INTERRELATIONSHIPS

Some aspects of the animal-sediment interrelationships on the Bermuda slope are clearly defined by this study. The importance of calcareous organisms as sediment formers is obvious. The destruction of sediments by organisms may well be an important process. The vast majority of the benthic fauna is infauna and probably predominantly indiscriminant sediment feeders. The passage of sedimentary particles through the guts of organisms may well modify the texture

and chemistry of the sediments significantly. Nothing is known about microbiological processes in the deep sea and their effects on the sediments.

It appears that the sediments likewise have an effect on the benthic organisms. The number of organisms per square meter on the Bermuda slope is significantly less, at a given depth, than on the North American continental slope. One obvious difference between the two areas is the nature of the substrate, carbonate on Bermuda and largely silicate on the continental slope. Associated with this mineralogic difference is, what preliminary data suggest, a difference in organic content of the sediments. The Bermuda slope appears to be about a factor of ten lower in organic carbon than the continental slope. Present analytical techniques are not entirely satisfactory for measuring small amounts of organic carbon in almost pure carbonate. New techniques are being studied, and we hope, a more definite statement on this important ecologic control will be possible in the near future.

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Table 1

Size Analyses of Bermuda Sediments

Sample	Weight Per Cent				
	>4000μ	4000-500μ	500-62μ	62-7.8μ	<7.8μ
SR 1	-	12.9	87.1	-	-
SR 2	0.8	64.0	35.2	-	-
SR 3	1.4	92.8	5.8	-	-
SR 4	0.5	95.0	4.5	-	-
SR 5	0.1	81.0	18.9	-	-
SR 6	5.1	94.1	0.8	-	-
SR 7	1.4	85.3	13.3	-	-
SR 8	1.5	74.4	24.1	-	-
SS 2	55.4	36.1	6.0	1.4	1.1
SS 3	44.3	41.3	11.7	1.2	1.4
SS 4	8.6	33.3	23.3	31.5	3.3
SS 6	-	13.2	32.7	45.0	9.1
SS 7	0.3	14.0	46.3	31.8	8.6
SS 8	-	31.8	36.5	24.4	7.2
SS 9	3.0	19.4	26.2	40.1	11.3
SS 11	5.9	29.2	35.9	20.7	8.4
SS 12	-	21.4	34.0	36.7	7.9
SS 14	6.1	11.7	24.1	49.3	8.8
SS 15	3.6	71.1	20.7	2.4	2.1
SS 16	11.2	37.7	39.1	8.3	3.7
SS 19	5.3	18.0	42.5	27.6	6.6
	>250μ	250-62μ	62-16μ	16-4μ	<4μ
DS 5	13.4	17.0	29.2	30.3	10.1
DS 6	1.9	37.2	36.4	12.4	12.0
DS 7	8.4	4.3	81.0	4.8	1.4

Table 2

Mineralogic Composition of Bermuda Sediments

<u>Per Cent Aragonite</u>

Sample	Size Fraction (microns)				
	4000-500	500-62	<62	<7.8	
SR 1	34	41	-	-	
SR 2	41	38	-	-	
SR 3	52	50	-	-	
SR 4	40	43	-	-	
SR 5	42	48	-	-	
SR 6	56	48	-	-	
SR 7	39	43	-	-	
SR 8	39	42	-	-	
SS 2	35	29	37	21	
SS 3	27	27	31	<10	
SS 4	26	26	34	14	
SS 6	16	30	40	32	
SS 7	22	25	36	31	
SS 8	28	29	34	29	
SS 9	35	26	39	23	
SS 11	26	28	37	30	
SS 12	30	35	40	19	
SS 14	<10	26	32	31	
SS 15	26	34	41	-	
SS 16	23	28	39	23	
SS 19	11	31	39	19	
	>250	250-62	<62	<16	<4
DS 5	23	22	22	11	<10
DS 6	26	28	34	19	17
DS 7	<10	35	21	11	<10

Table 3

Mineralogic Composition of Bermuda Sediments

<u>High to Low Magnesium Calcite Ratio</u>

Sample	Size Fraction (microns)				
	4000-500	500-62	< 62	< 7.8	
SR 1	1.4	2.9	-	-	
SR 2	2.4	3.1	-	-	
SR 3	5.2	2.5	-	-	
SR 4	1.9	2.1	-	-	
SR 5	2.0	1.7	-	-	
SR 6	3.0	2.1	-	-	
SR 7	1.5	1.0	-	-	
SR 8	1.2	1.6	-	-	
SS 2	1.3	1.0	1.0	1.1	
SS 3	1.1	0.9	0.9	0.9	
SS 4	0.9	1.1	1.3	0.8	
SS 6	1.2	0.9	1.1	0.8	
SS 7	0.8	0.9	1.2	1.0	
SS 8	1.3	0.9	1.2	1.0	
SS 9	0.7	0.8	1.3	0.9	
SS 11	1.1	1.1	1.1	1.0	
SS 12	2.8	1.2	1.0	0.7	
SS 14	1.0	1.0	1.4	1.2	
SS 15	0.8	1.5	0.9	-	
SS 16	1.2	2.1	1.3	0.8	
SS 19	0.4	0.9	1.4	0.9	
	> 250	250-62	< 62	< 16	< 4
DS 5	0.1	0.3	0.4	0.3	0.2
DS 6	0.6	1.2	1.6	1.1	0.7
DS 7	0.2	0.3	0.3	0.2	0.2

Table 4

Sediment Particles and their Probable Source

1. Pleistocene outcrops
    a. Rock fragments
    b. *Amphistegina lessoni*; the source of this Foraminifera is discussed at length in a later section.
2. Reef tract
    a. Scleractinian coral; *Diploria* sp., etc.
    b. Octacorals; spicules
    c. Foraminifera; *Homotrema rubra*, peneroplids
    d. Robust mollusks
    e. Encrusting algae; *Lithothamnium* (?), these extend somewhat deeper than 10 fathoms -- see discussion of algal balls.
3. Benthic organisms below 10 fathoms
    a. Non-reef benthic Foraminifera; rotalids, lagenids, etc., these are often quite fragile.
    b. Ostracods; probably epibenthic
    c. Delicate mollusks
    d. Branching Bryozoa; very fragile
4. Planktonic organisms
    a. Foraminifera; *Globigerina*, *Orbulina*, etc.
    b. Pteropods and heteropods; *Cavolina*, *Creseis*, *Atlanta*, etc.
5. Undefinable -- Miliolid Foraminifera, echinoderms, serpulid worm tubes, encrusting Bryozoa and some mollusks.

Table 5

Biologic Composition of Coarse Fractions*

Sample	Pleistocene		Reef tract					Benthic below 10 F.				Plankton		Undefined	
	Rocks	Amphistegina	Corals	Alcyonarians	Homotrema	Peneropids	Algae	Benthic Forams	Bryozoa	Mollusks	Ostracods	Planktonic Forams	Pteropods	Echinoids	Serpulids
SR 1-8	C	-	A	C	C	C	A	-	-	-	-	-	-	C	C
All SR samples are approximately the same.															
SS 2 4000-500μ	C	A	R	R	R	-	R	R	C	R	-	R	R	R	-
SS 2 500-62μ	C	C	C	C	-	-	?*	C	R	R	-	C	R	R	-
SS 3 4000-500μ	C	A	C	-	R	-	R	R	R	R	-	-	R	R	R
SS 3 500-62μ	C	A	R	C	R	-	?	A	R	R	R	C	R	R	-
SS 4 4000-500μ	C	D	C	R	R	-	C	R	R	R	-	R	R	R	-
SS 4 500-62μ	?	C	?	R	-	-	?	C	R	R	R	A	C	C	-
SS 6 4000-500μ	C	C	C	R	-	-	C	C	R	R	-	-	-	R	-
SS 6 500-62μ	?	-	R	R	-	-	R	R	R	R	R	A	C	R	-
SS 7 4000-500μ	R	A	?	-	C	-	C	C	R	R	-	C	R	R	-
SS 7 500-62μ	?	R	R	R	R	-	C	C	R	R	R	A	R	C	-
SS 8 4000-500μ	C	R	R	R	R	R	A	C	R	R	-	R	R	R	R
SS 8 500-62μ	R	-	C	-	-	-	C	C	R	R	R	A	R	R	-
SS 9 4000-500μ	C	R	R	-	-	R	R	R	C	R	-	A	A	R	-
SS 9 500-62μ	?	-	?	R	R	-	R	C	R	R	C	C	C	C	-

* When the physical condition of the specimens is poor it is difficult to distinguish rock fragments, corals, and algae. These cases are marked "?".

D = Dominant A = Abundant C = Common R = Rare

Table 5, continued

Biologic Composition of Coarse Fractions*

Sample	Pleistocene		Reef Tract					Benthic below 10 F.				Plankton		Undefined	
	Rocks	Amphistegina	Corals	Alcyonarians	Homotrema	Peneropids	Algae	Benthic Forams	Bryozoa	Mollusks	Ostracods	Planktonic Forams	Pteropods	Echinoids	Serpulids
SS 11 4000-500µ	C	D	R	-	R	R	R	C	C	R	R	R	R	R	R
SS 11 500-62µ	-	R	?	R	-	-	C	A	C	R	R	C	R	C	-
SS 12 4000-500µ	A	R	?	-	C	-	C	R	C	R	-	R	R	R	-
SS 12 500-62µ	C	-	-	-	-	-	C	C	C	R	C	C	C	R	-
SS 14 4000-500µ	C	D	R	-	R	-	R	C	R	-	-	C	R	-	-
SS 14 500-62µ	?	-	?	R	-	R	?	C	C	R	R	C	R	C	-
SS 15 4000-500µ	C	A	C	-	C	R	C	R	-	-	-	-	R	R	-
SS 15 500-62µ	C	R	C	C	R	R	R	R	R	R	R	-	R	R	-
SS 16 4000-500µ	A	C	C	-	R	R	C	-	R	-	-	-	R	R	R
SS 16 500-62µ	C	R	C	-	R	-	C	C	R	R	R	R	R	C	-
SS 19 4000-500µ	C	D	R	-	-	-	R	-	R	-	-	-	C	-	-
SS 19 500-62µ	R	C	R	-	R	-	R	C	C	R	R	C	C	C	-
DS 5 > 250µ	-	-	-	-	-	-	-	R	-	-	-	D	A	R	-
DS 6 > 250µ	-	-	-	-	-	-	-	C	C	R	C	A	A	A	-
DS 7 > 250µ	-	-	-	-	R	R	-	C	C	R	-	D	A	C	-

Table 6

Composition of the Living Populations

Station	No. Organisms	No./m^2	% Polychaetes
DS 5	70	149	61.4
DS 6	212	181	46.2
DS 7	105	138	32.4
DS 8 (1000 meters)	380	844	43.2

Table 7

Mineralogy of Common Bermuda Organisms

Organism	Environment	Mineralogy			
		Aragonite	Low Mg Calcite[1]	High Mg Calcite[1]	Aragonite & Calcite
Amphistegina lessoni	Pleist.		X		
Corals, scleractinian	Reef	X			
Corals, alcyonarian	Reef			X	
Homotrema rubra	Reef			X	
Peneroplid forams	Reef			X	
Algae	Reef	X		X	
Benthic forams	Above 450 F[2]			X	
Benthic forams	Below 450 F[2]		X		
Bryozoa	Slope	X			X
Mollusks	Slope	X	X		X
Ostracods	Intertidal[2]			X	
Ostracods	Sub-tidal[2]		X		
Planktonic forams	Water column		X		
Pteropods	Water column	X			
Echinoids	Above 400 F[2]			X	
Echinoids	Below 400 F[2]		X		

1. High and low magnesium calcite are as defined earlier -- greater and less than about 8 per cent $MgCO_3$.

2. Hydrographic data in Bermuda Biological Station Report AEC - AT(30-1)-2078, August 31, 1960, indicate that average temperatures on the Bermuda slope are approximately 25°-surface, 20°-50 fathoms, 15° - 350 fathoms, 10° - 450 fathoms, and 5° - 600 fathoms. The depths at which benthic Foraminifera, echinoids and ostracods change from high to low magnesium calcite are taken from magnesium-temperature curves in Chave (1954).

Table 8

Number of Animals in Deep Sea Sediments - Previous Work

Location	Number Animals	No./m^2
West Coast of Africa (Wolff, 1957)	1-17	5-85
Deep California basins (Hartman and Barnard, 1958)	2-25	11-123
Trenches (Wolff, 1960)	0-12	0-60
Northeast Pacific (Filatova and Levenstein, 1961)	1-17	5-85

Table 9

Number of Animals in Deep Sea Sediments - Present Investigation

Station	Location[1]	Depth (m)	No. Animals	No./m^2	% Polychaetes
C	a	100	3448	5945	46.5
E	b	1000	2943	2943	74.8
F	b	1500	1021	1726	73.0
G	b	2000	1251	2444	80.6
GH	c	2500	401	573	78.3
HH	c	2870	519	614	56.7
II	c	3750	449	1148 ?	43.7
JJ	d	4483	262	262	51.8
KK	e	4812	123	100	62.6
LL	e	4977	66	54	48.5
MM	e	5001	26	32	53.9
DS 7[2]	f	2500	105	138	32.4
DS 5[2]	f	2000	70	149	61.4
DS 6[2]	f	1500	212	181	46.2
2	f	1700	194	299	
3	f	1700	126	282	
4	f	1700	230	232	
1	f	1000	239	517	
DS 8[2]	f	1000	380	844	43.2

1. a - outer continental shelf; b - continental slope off New England; c - abyss north of Gulf Stream; d - Gulf Stream; e - Sargasso Sea; f - Bermuda Slope

2. Samples discussed in this report.

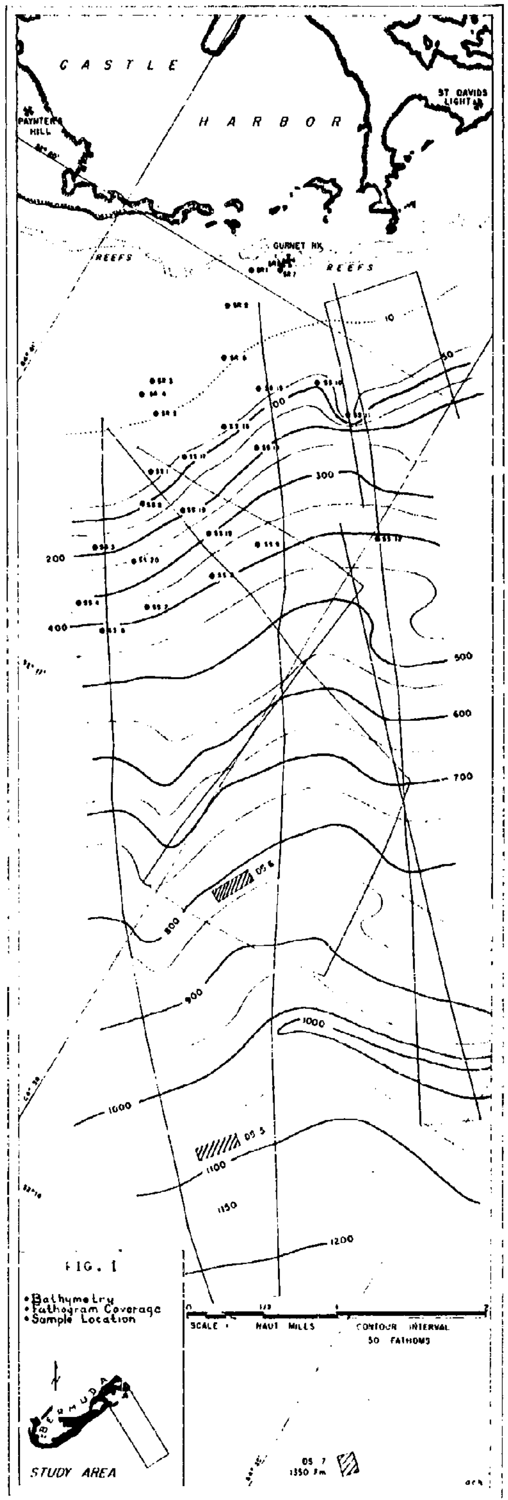

CASTLE
HARBOR
PAYNTERS HILL
ST DAVIDS LIGHT
GURNET RK
REEFS
REEFS
10
50
100
200
300
400
500
600
700
DS 6
800
900
1000
1000
DS 5
1100
1150
1200
FIG. I
• Bathymetry
• Fathogram Coverage
• Sample Location
SCALE
NAUT MILES
CONTOUR INTERVAL
50 FATHOMS
BERMUDA
STUDY AREA
DS 7
1350 Fm

Fig. I

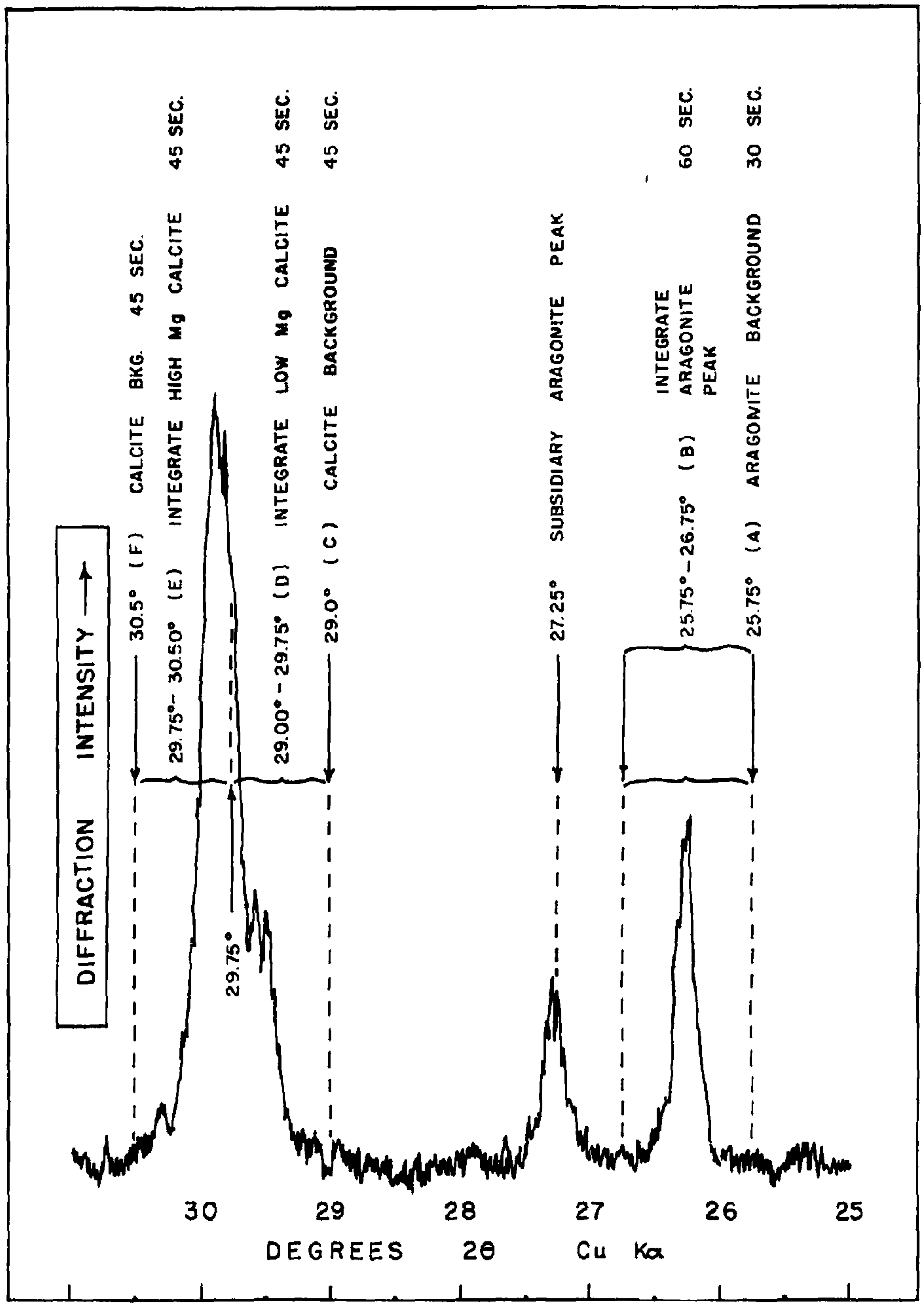

DIFFRACTION INTENSITY →
30.5° (F) CALCITE BKG. 45 SEC.
29.75°- 30.50° (E) INTEGRATE HIGH Mg CALCITE 45 SEC.
29.00° - 29.75° (D) INTEGRATE LOW Mg CALCITE 45 SEC.
29.0° (C) CALCITE BACKGROUND 45 SEC.
27.25° SUBSIDIARY ARAGONITE PEAK
25.75° - 26.75° (B) INTEGRATE ARAGONITE PEAK 60 SEC.
25.75° (A) ARAGONITE BACKGROUND 30 SEC.
29.75°
30 29 28 27 26 25
DEGREES 2θ Cu Kα

Fig. 2

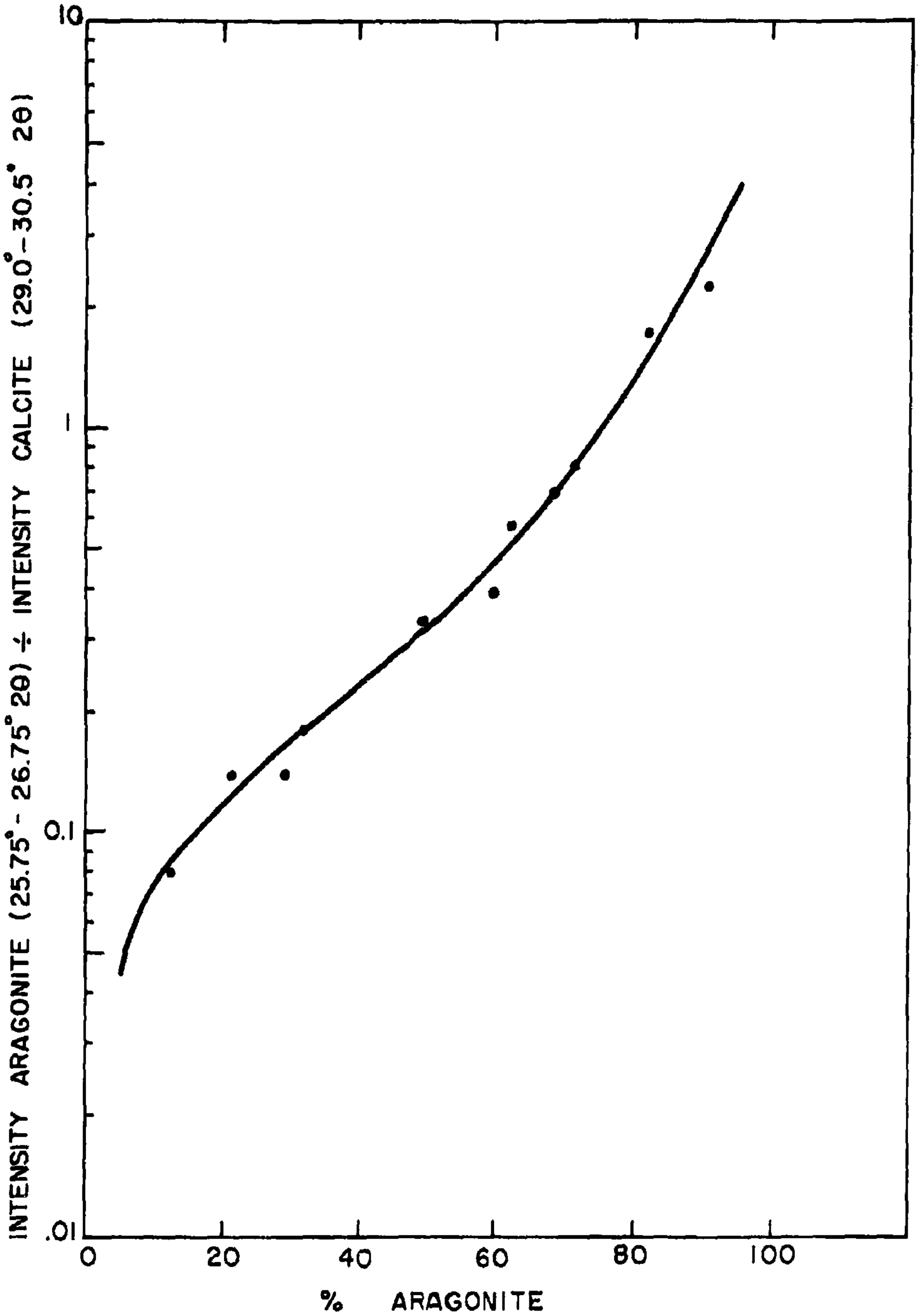

INTENSITY ARAGONITE (25.75°- 26.75° 2θ) ÷ INTENSITY CALCITE (29.0°-30.5° 2θ)
10
1
0.1
.01
0
20
40
60
80
100
% ARAGONITE

Fig. 3

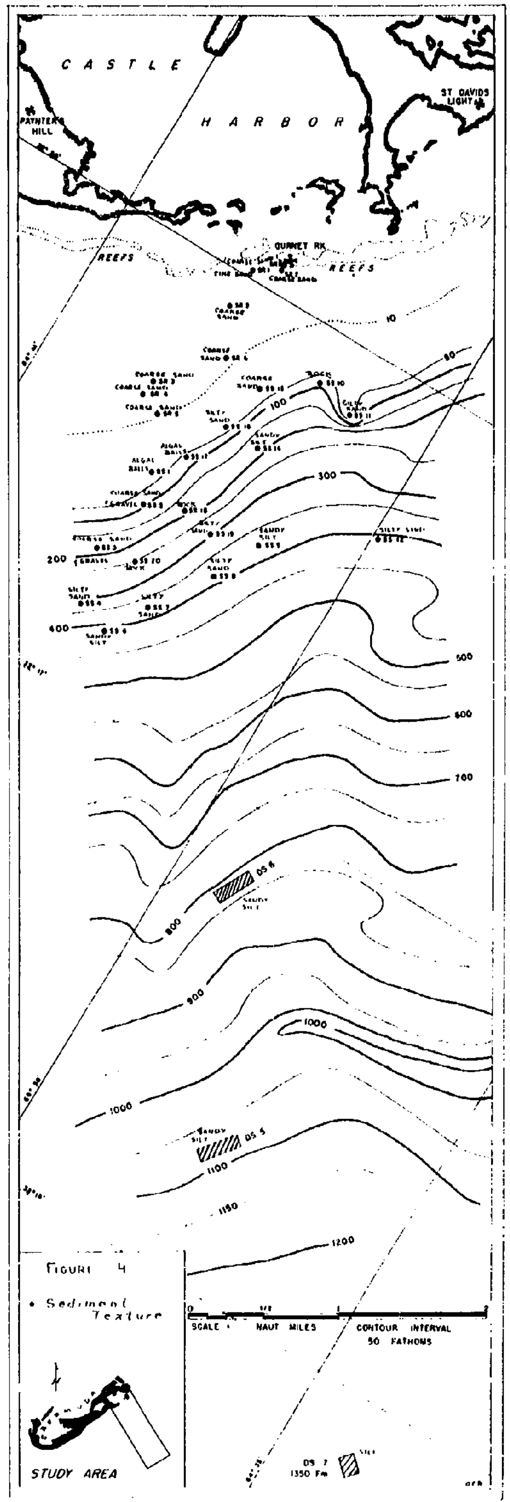

CASTLE
HARBOR
PAYNTER'S HILL
ST DAVIDS LIGHT
GURNET RK
REEFS
REEFS
FIGURE 4
• Sediment Texture
STUDY AREA
SCALE NAUT MILES
CONTOUR INTERVAL 50 FATHOMS
DS 6
DS 5
DS 7
1350 Fm
100
200
300
400
500
600
700
800
900
1000
1100
1150
1200

Fig. 4

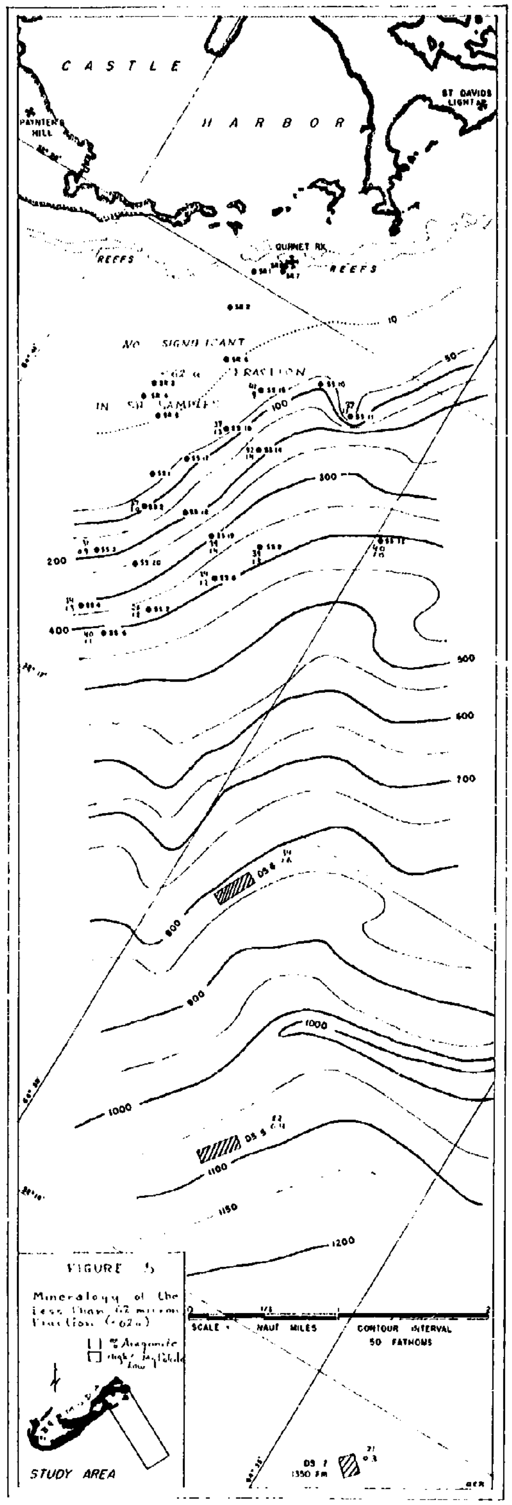
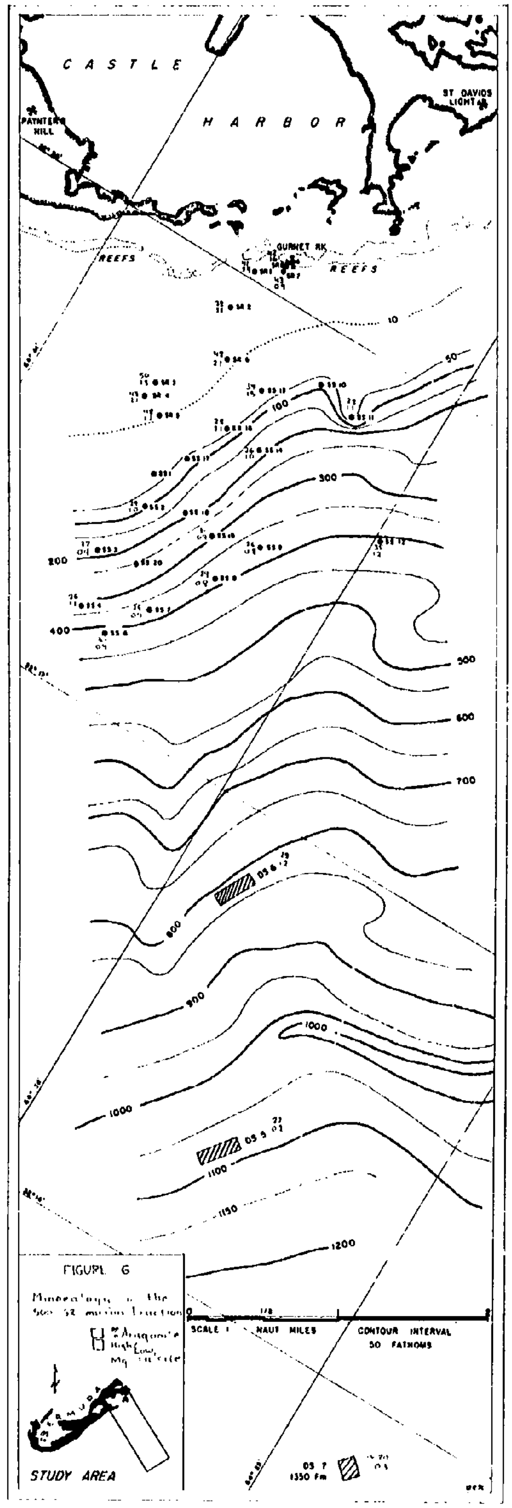

CASTLE
HARBOR
PAYNTER'S HILL
ST DAVIDS LIGHT
GURNET RK
REEFS
REEFS
NO SIGNIFICANT
<62 u FRACTION
IN SH SAMPLES
FIGURE 5
SCALE
NAUT MILES
CONTOUR INTERVAL
50 FATHOMS
STUDY AREA

Fig. 5



CASTLE
HARBOR
PAYNTERS HILL
ST DAVIDS LIGHT
GURNET RK
REEFS
REEFS
10
50
100
200
300
400
500
600
700
800
900
1000
1000
1100
1150
1200
FIGURE 6
SCALE
NAUT MILES
CONTOUR INTERVAL
50 FATHOMS
1350 Fm
STUDY AREA

Fig. 6

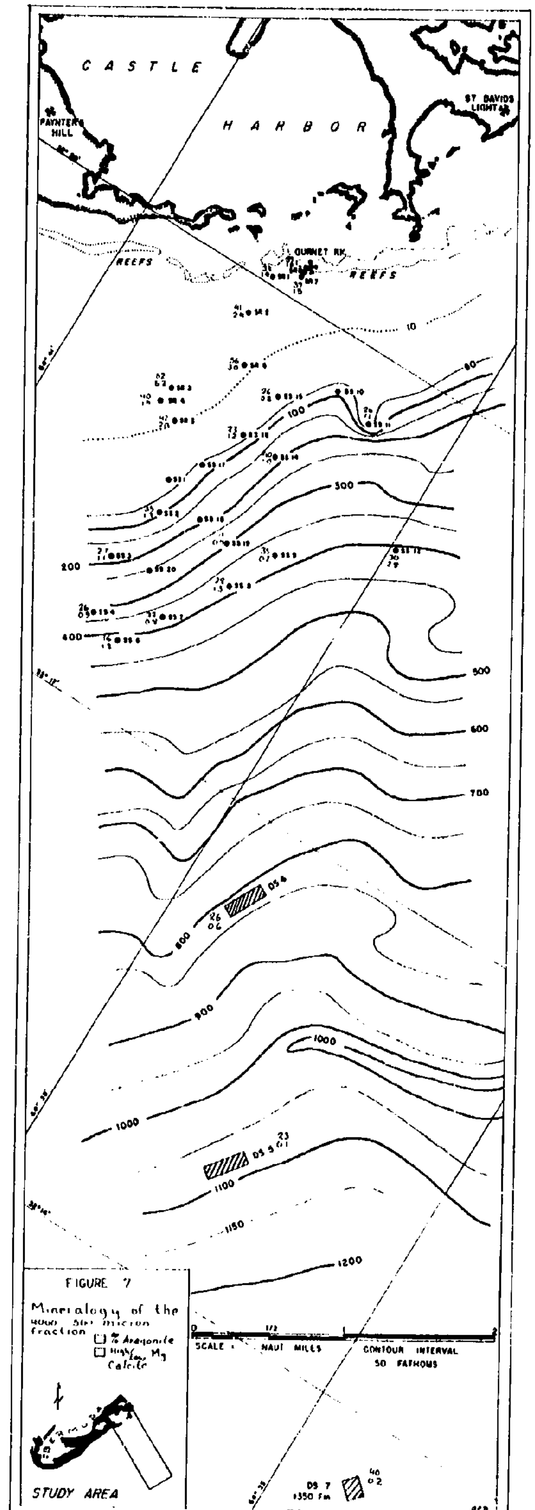
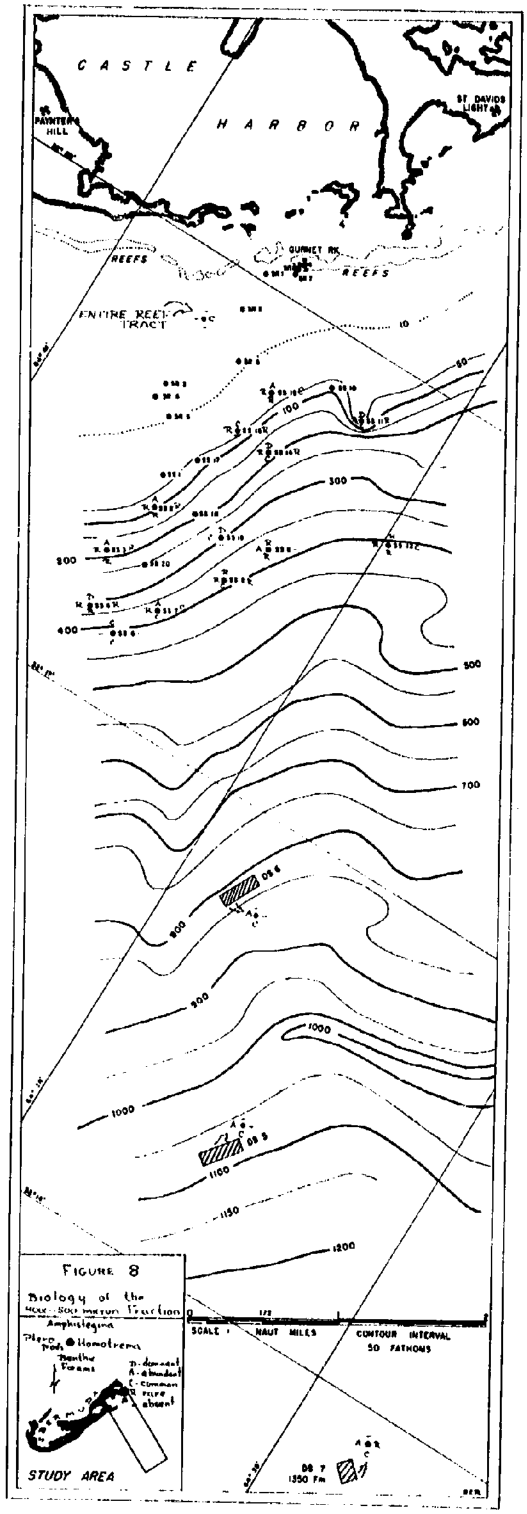

CASTLE
HARBOR
PAYNTERS HILL
ST DAVIDS LIGHT
GURNET RK.
REEFS
REEFS
10
60
100
200
300
400
500
600
700
800
900
1000
1000
1100
1150
1200
FIGURE 7
Mineralogy of the
fraction
% Aragonite
High/Low Mg Calcite
STUDY AREA
SCALE
NAUT MILES
CONTOUR INTERVAL
50 FATHOMS
DS 7
1350 Fm

Fig. 7



CASTLE
HARBOR
ST DAVIDS LIGHT
PAYNTER'S HILL
REEFS
GURNET RK.
REEFS
ENTIRE REEF TRACT
300
500
600
700
800
900
1000
1100
1150
1200
FIGURE 8
Biology of the
400-500 micron Fraction
Amphistegina
Ptero pods
Homotrema
Benthic Forams
D - dominant
A - abundant
C - common
R - rare
absent
BERMUDA
STUDY AREA
SCALE 1 NAUT MILES
CONTOUR INTERVAL 50 FATHOMS
DS 7
1350 Fm

Fig. 8